Ω^- Hyperon Decay Modes with the HyperCP Experiment at Fermilab.

Prof. Nickolas Solomey [a]

[a]Illinois Institute of Technology, Chicago, USA

The HyperCP experiment (Fermilab E871) has the largest recorded sample of Ω^- hyperon decays, allowing new searches for three rare decay modes, each with five charged tracks in the final state. Results are presented for $\Omega^- \to \Xi^-\pi^+\pi^-$; $\Omega^- \to \Xi^0(1530)\pi^-$; and the flavor-changing neutral-current decay $\Omega^- \to \Xi^-\mu^+\mu^-$. Normalization of these measurements were to the decay $\Omega^- \to \Lambda K^-$ with a five-track topology similar to the signal mode with the subsequent decay of $\Lambda \to p\pi^-$ and $K^- \to \pi^-\pi^+\pi^-$ in the decay volume.

1. Theoretical Background

The Ω^- hyperon with three strange quarks is of great theoretical interest because of its unique ability to tell us about the processes involved in the decay [1]. However to be able to actually use this wonderful tool provided by nature it is first necessary to obtain a large sample of interesting decays. The HyperCP experiment has made great progress in this pursuit with a recent observation of a rare decay mode.

The decays of interest and their theoretical expected [2] or previously reported Branching Ratios (BR) are:

$$\begin{aligned}
\Omega^- \quad &\to \quad \Xi^-\gamma \qquad 1.6\times10^{-4} && (1)\\
&\to \quad \Xi^-\pi^+\pi^- \quad 4.3\times10^{-4} \quad [3] && (2)\\
&\to \quad \Xi^-e^+e^- \quad 1.4\times10^{-6} && (3)\\
&\to \quad \Xi^-\mu^+\mu^- \quad 6.6\times10^{-8} && (4)
\end{aligned}$$

(The equivalent anti-particle processes are also of interest.) All of these decay modes have a high-Q released energy and should not be limited by phase space. The radiative decay mode listed first has yet to be seen, but it has a high theoretical BR. The second decay mode has many possible suppressed feynman diagrams that can contribute (such as tree, penguin, and double-Zweig) and perhaps others due to new particles including higgs or supersymmetry, but experimentally it has a substantial BR. The last two decays are flavor-changing neutral currents, which have never been seen with hyperon decays.

Observation of these decays, especially with high statistics, can be a useful tool for both probing the accuracy of the standard model, and as a means to look for new physics. A large decay sample can be useful for more than just the BR measurement. The subsequent decay of the Ξ^- can tell us about the decay itself by using its analyzing power to look for an asymmetry in the decay [4], similar to that done with other hyperon radiative decays [5].

There are also two other processes that can contribute to the decay in equation (2). These are when the final observed five tracks have gone through a short lived resonance:

$$\begin{aligned}
\Omega^- \quad &\to \quad \Xi^0(1530)\ \pi^- && (5)\\
&\qquad \to \Xi^-\pi^+ &&\\
&\to \quad \Xi^-\sigma^0(400) && (6)\\
&\qquad\quad \to \pi^+\pi^- &&
\end{aligned}$$

Observation of the $\sigma^0(400)$ would be important since the existence of this state is highly debated and has never been observed in any decay chain. Its mass value is stated in the PDG as being from 400 to 1200 Mev/c^2 and its Breit-Wigner width is anywhere from 600 to 1000 MeV/c^2! All of these parameters could be resolved if this particle is studied in a decay.

2. New Results in Ω^- Decays

The HyperCP experiment E871 at Fermilab took data in 1997 and 1999 [6]. The experiment is depicted in figure 1. It was designed to search for CP violation in Hyperons [7]. The 800 GeV/c proton beam hit a target at the entrance of a hyperon channel with a nominal momentum of 170

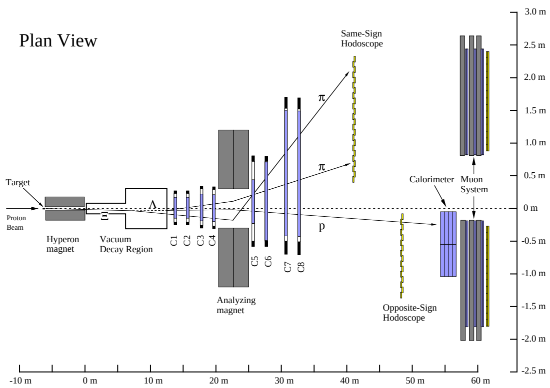

Figure 1. A schematic depiction of the E871 HyperCP experiment at Fermilab.

GeV/c and a bite of ± 35 GeV/c FWHM. The experiment's decay volume started at the exit of the hyperon channel and was 13 meters long. The experiment itself is a charged particle tracking spectrometer, with 4 MWPC before a high-field analysis magnet and 4 MWPC after the analysis magnet. These were followed by a hodoscope of 10-cm wide vertical paddles in the positive and negative arms of the spectrometer. There was a muon identification system further downstream that consisted of a muon hodoscope and three layers of steel and proportional tubes.

The trigger of the experiment consisted of at least two charged tracks of opposite polarity and energy in the calorimeter, which was a combination electromagnetic and hadronic calorimeter. The experiment wrote more than 40,000 5Gb Exabyte data tapes. These raw data tapes were processed to produce different output data streams which had further requirements such as three charged tracks, good masses, and identified muons depending upon the intended physics use of each stream. Anti-particle processes (referred to as "positive" data) were studied in the same spectrometer under identical conditions (except for their production momentum spectra and daughter-particle interaction cross sections) by reversing the magnetic field in the hyperon channel and analysis magnets.

The results presented here come from an analysis of the stream with at least three charged tracks for the decay mode $\Omega^- \to \Xi^-\pi^+\pi^-$ and at least three charged tracks plus two opposite polarity muon tracks for the decay mode $\Omega^- \to \Xi^-\mu^+\mu^-$. The selection cuts were devised with a blind analysis on signal, normalizing and background modes generated with a dedicated Monte-Carlo simulation program. The cuts used in this analysis were: (a) three negative and two positive tracks, (b) all decay vertices inside the decay volume, (c) vertex topology consistent with the intended decay, (d) total Ω^- momentum between 120 and 220 GeV/c, (e) all reconstructed masses within ± 3 sigma of their nominal mass, and (f) the reconstructed Ω^- track appeared to come from the aperture of the hyperon channel exit. For the muon decay mode of equation (4) an additional requirement from the muon identification system was imposed. For the $\overline{\Omega}$, the number of different charged particles required was inverted.

Normalization of the candidate events could be done with both the five- and three-track decays $\Omega^- \to \Lambda K^-$ where the K^- either does or does not decay into three charged pions. In either case the Λ decays into proton and π^-. The five-track decay mode is the most valuable decay for normalization since the topology is very similar to the signal modes and is the one used in all BR calculations presented here. The Monte-Carlo was used for acceptance corrections among the various modes. For the signal mode of equation (2) a uniformly populated phase space generator was used. The Monte-Carlo was also used to simulate possible backgrounds before opening the signal box. At that stage of the analysis there was confidence that no significant backgrounds to these decay modes existed.

3. Observations and Measurements

The full HyperCP data sample was analyzed [8]. The observed "negative" five-track signal of the decay $\Omega^- \to \Xi^-\pi^+\pi^-$ is shown in figure 2, and the normalization was done with the five-

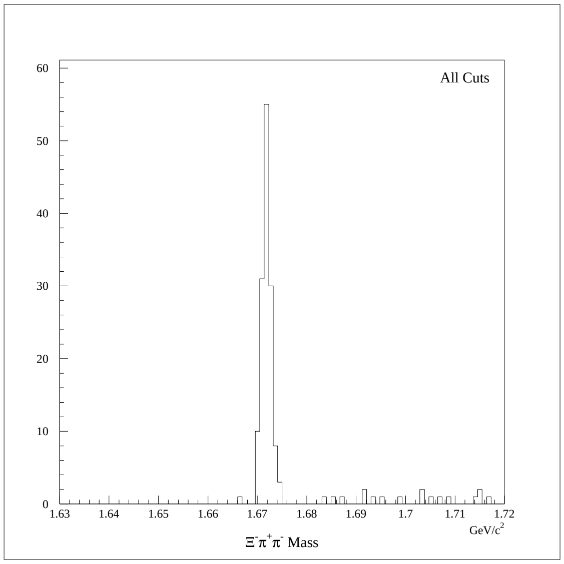

Figure 2. The observed events for the five-track signal mode of equation (2) is shown with all of the negative hyperon beam data.

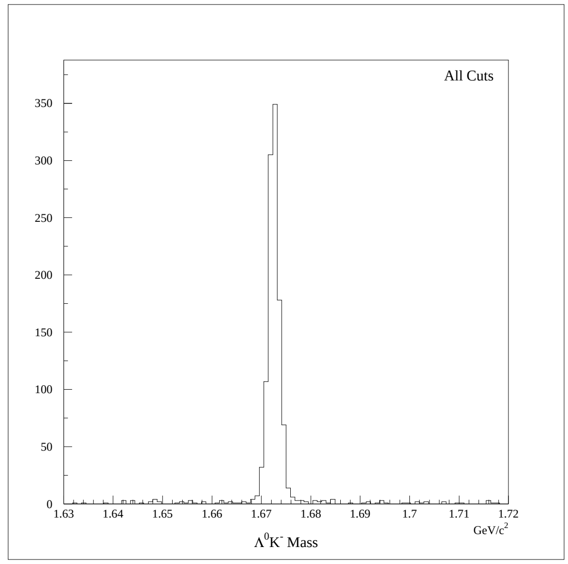

Figure 3. The observed events for the five-track normalizing mode $\Omega^- \to \Lambda K^-$ where the K^- decays into three charged pions and the Λ into $p\pi^-$ in the experiment's decay volume before the first MWPC, for all of the negative hyperon beam data.

track decay mode $\Omega^- \to \Lambda K^-$ where $K^- \to \pi^-\pi^+\pi^-$ and $\Lambda \to p\pi^-$ shown in figure 3. When combined with the acceptance correction from Monte-Carle simulation and the appropriate known BR from the PDG [9] it permitted measuring

$$BR(\Omega^- \to \Xi^-\pi^+\pi^-) = \frac{N_{\Omega^-\to\Xi^-\pi^+\pi^-}}{N_{\Omega^-\to\Lambda K3pi^-}}\frac{A_{\Omega^-\to\Lambda K3pi^-}}{A_{\Omega^-\to\Xi^-\pi^+\pi^-}} \times \frac{BR(\Omega^-\to\Lambda K^-)\times BR(K^-\to\pi^-\pi^+\pi^-)}{BR(\Xi^-\to\Lambda\pi^-)}. \tag{7}$$

All data sets and their combinations yields statistically consistent results as shown in figure 4. The signal events within ± 3 sigma were used, and the background under the signal peak was estimated using the side bands at $\pm 7-11$ sigma.

4. Conclusion

The final combined preliminary BR for this decay mode is 3.6×10^{-4} with a statistical error of $\pm 0.3 \times 10^{-4}$, which is slightly better than a 10% measurement. The HyperCP data sample was also used to measure the $\overline{\Omega}$ hyperon (referred to in the graph as "Pos." data), and this yields a very similar result within errors. The full data sample was also used to look for the flavor-changing neutral-current decay modes with muon pairs. No candidate events were observed yielding a preliminary BR limit with only the negative data as $< 1 \times 10^{-4}$ at the 90% confidence level.

A first look at the resonance mode of equation (5) shows no clear sign of its existence (see figure 5), but the $\Xi^0(1530)$ is a wide resonance and spin has not yet been taken into account in the

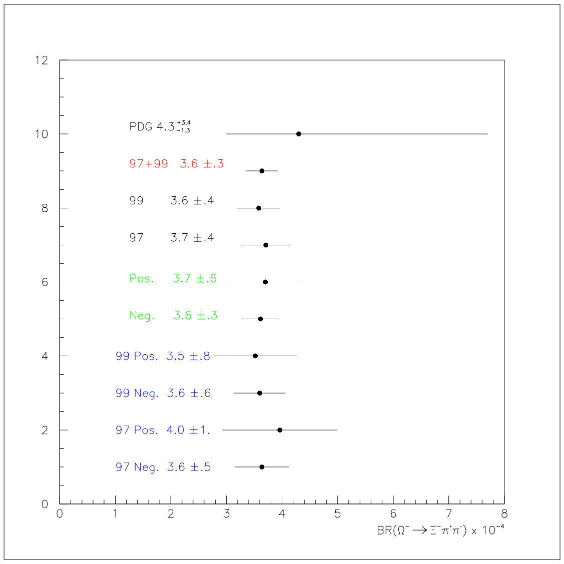

Figure 4. Preliminary BR for the $\Omega^- \to \Xi^-\pi^+\pi^-$ for all four data samples and various combinations. Errors are statistical only.

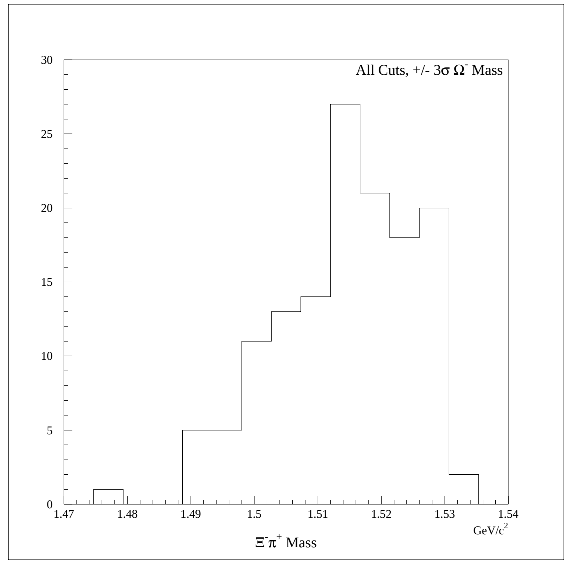

Figure 5. Using only those Ω^- within ± 3 sigma of its known mass, the $\Xi^0(1530)$ resonance is not immediately evident.

Monte-Carlo simulation of this decay so the exact expectations of its signature may be not be an obvious peak.

Further work is needed to refine these results and their associated systematic errors which are not worse than these statistical errors. There are also plans to use this data to understand what, if anything, resonance decays could be contributing. Furthermore, by using the self-analyzing power of the Ξ^- decays it should be possible to look for any asymmetries of the $\pi^+\pi^-$ pair, similar to the asymmetry seen in hyperon radiative decays, to yield clues to the decay mechanism.

Acknowledgments

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